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# STUDIES IN SAMPLING TECHNIQUE: CEREAL EXPERIMENTS.

## III. RESULTS AND DISCUSSION.

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(With One Text-figure.)

AFTER threshing there were three sets of figures, representing total weights of sheaflets, weights of grain, and weights of straw. These were subjected to an analysis which aimed firstly at obtaining a direct estimate of the sampling-error, and secondly at comparing the significant results of the experiment, treated as a manurial trial, with those obtained from the "total yields." The analysis was also designed to show whether it was really of value to divide the plot into two or more parts from each of which equal numbers of metre-lengths were cut.

The first step consisted in summing sheaflet yields (whether total, of grain or of straw) and squares of yields, for each half-plot and plot. The plot totals were then compounded in various ways to give sums of sheaflet yields and of squares of sheaflet yields for each block of plots and for each treatment. The grand totals of sheaflet yields and of sums of squares were also calculated.

From these quantities it is no difficult matter to find the total sum of squares of deviations of sheaflet yields from the mean sheaflet yield. This total can be divided into two parts, one representing variations *between* and one *within* half-plots. The former can be further divided into variations *between* different plots, and variations between half-plots *within* the same plot. The variation between plots is now divisible into fractions representing variation between blocks of plots; variation between manurial treatments; and lastly, variation due to uncontrolled causes, such as differences in soil fertility between plots in the same block; errors of area measurement, of weighing the manures, etc.; and errors due to sampling. This last fraction affords a basis for estimating the standard error of treatment comparisons.

The labour of calculation was much lessened by the use of a calculating machine.

## 1. ROTHAMSTED WINTER OATS EXPERIMENT.

In this experiment there were sixteen different manurial treatments, and each occurred three times, once in each of three compact "blocks" of plots, the position within the block being assigned at random. The arrangement was therefore an example of Fisher's "Randomised Blocks" method for field experimentation. The sixteen treatments were selected to give as much information as possible about the relative values of sulphate of ammonia and cyanamide, both as spring and autumn dressings. The unit dressing was in all cases equivalent to  $\frac{3}{4}$  cwt. per acre of cyanamide with 19.0 per cent. N. One plot in each block received no dressing; four received single units; six received pairs of different units; four received three different units; and one received all four units. The table shows the manurial scheme.

Table I.

Treatment no.	Treatment				Treatment no.	Treatment			
1	—	—	—	—	9	—	Ss	Ca	—
2	Sa	—	—	—	10	—	Ss	—	Cs
3	—	Ss	—	—	11	—	—	Ca	Cs
4	—	—	Ca	—	12	Sa	Ss	Ca	—
5	—	—	—	Cs	13	Sa	Ss	—	Cs
6	Sa	Ss	—	—	14	Sa	—	Ca	Cs
7	Sa	—	Ca	—	15	—	Ss	Ca	Cs
8	Sa	—	—	Cs	16	Sa	Ss	Ca	Cs

Sa = Sulphate of ammonia applied in autumn.  
 Ca = Cyanamide applied in autumn.  
 Ss = Sulphate of ammonia applied in spring.  
 Cs = Cyanamide applied in spring.

By selection of the appropriate groups of plots it is possible to find the effect of each unit dressing separately, and their "interactions" when two, three or four are present. Every plot can be used for each of these comparisons, so that the arrangement is one of high efficiency.

As has already been stated, the plots, 48 in number, were each  $\frac{1}{40}$ th acre in area, and 30 metre-lengths (15 from each half-plot) were cut from each.

Tables II and III give the complete analyses for grain and straw, both for yields estimated from samples and for "actual yields," obtained by the use of large-scale methods.

The entries in the column headed "Mean square" are obtained from those in the "Sum of squares" column by dividing by the appropriate number of degrees of freedom.

Dealing first with the analysis of "sampling yields," comparison of

Table II.

*Sampling yields (gm. per sampling-unit).*

Fraction	Degrees of freedom	Grain		Straw	
		Sum of squares	Mean square	Sum of squares	Mean square
Blocks	2	1,879.78	939.89	3,838.18	1919.09
Sa	1	8.87	8.87	288.19	288.19
Ss	1	2,014.03	2014.03*	23.46	23.46
Ca	1	1,186.28	1186.28	3,549.46	3549.46
Cs	1	632.03	632.03	2,795.03	2795.03
Sa Ss	1	22.00	22.00	904.40	904.40
Sa Ca	1	238.47	238.47	330.43	330.43
Sa Cs	1	86.53	86.53	94.66	94.66
Ss Ca	1	1,895.21	1895.21*	825.37	825.37
Ss Cs	1	1,713.92	1713.92*	2,188.43	2188.43
Ca Cs	1	22.25	22.25	1,831.06	1831.06
Sa Ss Ca	1	18.45	18.45	158.14	158.14
Sa Ss Cs	1	146.94	146.94	225.47	225.47
Sa Ca Cs	1	35.47	35.47	148.74	148.74
Ss Ca Cs	1	11.74	11.74	767.38	767.38
Sa Ss Ca Cs	1	735.31	735.31	1,102.85	1102.85
Experimental error	30	9,532.16	317.79	28,602.78	953.43
Between half-plots	48	14,268.42	297.26	24,620.84	512.93
Within half-plots	1343	96,328.30	71.73	227,333.66	169.27
Total	1438	130,776.16	—	299,628.52	—

Table III.

*“Actual” yields ( $\frac{1}{2}$  lb. per plot).*

Fraction	Degrees of freedom	Grain		Straw	
		Sum of squares	Mean square	Sum of squares	Mean square
Blocks	2	2,083.04	1041.52	5,755.17	2877.58
Sa	1	75.00	75.00	3,960.33	3960.33*
Ss	1	3,780.75	3780.75*	2,730.08	2730.08*
Ca	1	1,365.33	1365.33*	4,485.33	4485.33*
Cs	1	140.08	140.08	3,780.75	3780.75*
Sa Ss	1	261.33	261.33	4.09	4.09
Sa Ca	1	2.09	2.09	16.34	16.34
Sa Cs	1	8.34	8.34	234.09	234.09
Ss Ca	1	1,976.34	1976.34*	5,084.09	5084.09*
Ss Cs	1	720.75	720.75	5,896.34	5896.34*
Ca Cs	1	1,045.34	1045.34	36.75	36.75
Sa Ss Ca	1	420.08	420.08	200.07	200.07
Sa Ss Cs	1	972.00	972.00	456.32	456.32
Sa Ca Cs	1	352.07	352.07	6.74	6.74
Ss Ca Cs	1	40.33	40.33	47.99	47.99
Sa Ss Ca Cs	1	330.75	330.75	1,160.36	1160.36
Experimental error	30	7,934.30	264.48	15,314.83	510.49
Total	47	21,507.92	—	49,169.67	—

the mean squares corresponding with "between half-plots" and "within half-plots" by means of Fisher's "z" test, shows that both for grain and straw the former is the larger by an amount which would not occur merely by chance as often as once in twenty times. It may be concluded, then, that it has been advantageous to divide the plots transversely, and to take half the total number of metre-lengths from each half-plot. For had this not been done, there would have been plots on which the metre-lengths came nearly all from one half; and the accuracy of the yield estimate would have been diminished, since the two halves are shown to differ significantly.

The fraction "within half-plots" represents the variation between metre-lengths of the same half-plot, and provides a direct estimate of the sampling-error, since all variation due to treatment and position of the plot, and to differences between half-plots of the same plot, are here eliminated. The square root of the mean square gives the sampling-error of a single metre-length. Since there are 30 metre-lengths from each plot, the sampling-error of a plot mean is obtained from this by dividing by  $\sqrt{30}$ .

By treating the "experimental error" mean square in exactly the same way, an estimate is obtained of the variability of the "sampling yield" of a single plot when correction has been made for the average fertility of the block in which it falls, and for the manurial treatment which it has received. It thus includes errors due to sampling as well as those due to differences in fertility between plots of the same block, and to working errors; and is the appropriate basis for determining the significance of manurial effects.

In the case of "actual yields" only one of these quantities can be calculated—the experimental error per plot—and this is simply the square root of the corresponding mean square.

Table IV gives the values of these errors for grain and straw, and for both sets of data.

Table IV.

	Grain			Straw		
	Mean square	Standard error	Standard error per cent. per plot	Mean square	Standard error	Standard error per cent. per plot
(a) "Sampling yields":						
Experimental error	317.74	3.254	12.36	953.43	5.638	13.09
Within half-plots	71.73	1.546	5.87	169.27	2.375	5.51
(b) "Actual yields":						
Experimental error	264.48	16.26	11.07	510.49	22.59	7.90

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The sampling-errors are higher than the expected 5 per cent. per plot. This is almost certainly due to winter mortality, many plants being killed by the severe frosts of February, 1928. Despite this the experimental error per plot has been only slightly increased in the case of grain (11.07 to 12.36 per cent.). The increase is more serious for straw (7.90 to 13.09 per cent.): reasons for this will be discussed later.

The real test of the adequacy of a sampling method is the comparison of the amount of information obtained by its use, with that obtained when large-scale methods are employed. Tables II and III give complete analyses of the effect of the various manurial treatments. The test of significance consists in comparing, by means of the "z" distribution, the appropriate mean square with the "experimental error" mean square. Those items which show a significantly higher variation than that due to experimental error (taking odds of 1 in 20 as the level of significance) are marked with an asterisk. It will be seen that, for grain, both sets of data yield three significant items, of which two are common, Ss, and the first order interaction SsCa. The autumn application of cyanamide (Ca), which would be judged effective on the basis of the analysis of "actual yields," just fails to reach the 1 in 20 level in the analysis of "sampling yields"; and the first order interaction of the two spring dressings (SsCs) is significant in the latter but not in the former analysis. Substantially the same results are thus obtained by the two methods: the differences may be due to differences in the mesh of the dressing screens.

For straw the differences are much more striking. While no less than six items are starred in Table III, there are none in Table II (Ca just fails to reach the 1 in 20 level). This is the more curious in that the sampling-error per plot is actually lower for straw (5.51 per cent.) than for grain (5.87 per cent.). Two factors seem to be at work here. In the first place the height above ground at which the straw was cut was constant for the large-scale method, where a binder was used; but varied a little from plot to plot where several different workers were cutting samples. Secondly, the crop was very weedy, owing to the thinness of the plant after the winter frosts, and since all the weeds were included in the "large-scale" sheaves, but were partially discarded from the sampling sheaflet, the yields of straw would be expected to differ on this account. The effect of the first factor would be to increase the experimental error as calculated from the sampling data. This would tend to obscure real effects of manurial treatment. A hint that this surmise is correct is obtained by comparing the difference between the two

estimates of experimental error with the sampling-error. If the only important additional source of variation is the sampling technique, then

$$V_s = V_1 - V_2,$$

where  $V_s$  = relative variance due to sampling,

$V_1$  = relative variance corresponding with experimental error for "sampling" yields,

$V_2$  = relative variance corresponding with experimental error for "actual" yields.

For the relative variances we may use the squares of the sampling and experimental percentage errors. Then, for grain:

$$V_s = 5.87^2 = 34.46; V_1 - V_2 = 12.36^2 - 11.07^2 = 30.23$$

and the agreement is good.

For straw, however:

$$V_s = 5.51^2 = 30.36; V_1 - V_2 = 13.09^2 - 7.90^2 = 108.94.$$

There is here a considerable difference in the expected direction, supporting the view that the experimental error calculated from the sampling data differs from that calculated from the "actual" yields by another important factor in addition to the sampling-error, this being the variation in the length of straw cut from the different plots.

Support for the second assumption is found in comparing the estimates of average yield and the ratios of straw to grain obtained by the two methods (Tables V and VI).

Table V. *Mean yield in cwt. per acre.*

Grain	"Actual yields"	...	...	13.12
	"Sampling yields"	...	...	13.77
Straw	"Actual yields"	...	...	25.54
	"Sampling yields"	...	...	22.52

Table VI. *Ratio of straw to grain.*

"Actual yields"	...	...	...	1.95
"Sampling yields"	...	...	...	1.64

Here the estimates of mean yield of straw differ by more than 12 per cent. in favour of the large-scale method, as would be expected if a considerable quantity of weed were weighed with the sheaves. Further evidence for this view is that the discrepancies between the estimates of straw yield are greater for plots receiving sulphate of ammonia than

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for plots receiving cyanamide, a result to be expected if cyanamide depresses the germination of weed seeds.

This is an important conclusion, since the significant effects which emerge from analysis of the "actual yields" are now under suspicion as being probably due in part to differences in amount of weed infestation. The sampling method, it should be noted, provides a means of estimating this disturbing factor on experimental plots, or, alternatively, of eliminating it.

### 2. ROTHAMSTED BARLEY EXPERIMENT.

The arrangement of this experiment has already been described (p. 367). The important feature from the point of view of the sampling method was that each of the 50 plots was divided into quarters, 1/160th acre in area, which received different manurial treatments. The separate harvesting of these quarter-plots was effected only by the sampling method; the task would have been very difficult or impossible if large-scale machinery had to be employed.

The sampling and experimental errors are shown in Table VII.

Table VII.

	Grain		Straw	
	Whole plot	Quarter-plot	Whole plot	Quarter-plot
A. Square at the lower level of nitrogen.				
(a) "Sampling yields":				
Experimental error	5.58	13.70	13.56	14.99
Sampling-error	5.53	11.07	5.58	11.17
(b) "Actual yields":				
Experimental error	8.46	—	10.04	—
B. Square at the higher level of nitrogen.				
(a) "Sampling yields":				
Experimental error	6.98	10.64	7.58	11.71
Sampling-error	4.99	9.97	5.09	10.19
(b) "Actual yields":				
Experimental error	3.77	—	6.26	—

The sampling-errors for whole plots are those of means of 32 sampling-units, and are comparable with the values obtained in the winter oats experiment, 5.87 per cent. for grain and 5.51 per cent. for straw. It will be seen that the expected value of about 5 per cent. was obtained in plots which received the double quantity of nitrogen. It is almost invariably found, as here, that an area bearing a heavy crop gives smaller experimental errors than one otherwise similar but with a light crop. The fact that the sampling-errors are also smaller suggests that the ex-



planation lies in the greater capacity of a heavily manured crop to compensate for unevenness in the original plant. In a cereal crop this compensation usually takes the form of an increased number of ear-bearing tillers on the plants adjoining gaps.

The very small experimental error for "actual yields," especially of grain, in plots receiving the heavy dressing, exaggerates the difference between the two methods of harvesting. An error as low as 3.77 per cent. must be regarded as exceptional, however; usually the plot error falls between 6 and 12 per cent. of the mean yield.

Only eight sampling-units were taken from each quarter-plot, and the sampling-errors are double those for whole plots.

Table VIII. "Sampling yields" (gm. per quarter-plot).

Fraction	Degrees of freedom	Grain		Straw	
		Sum of squares	Mean square	Sum of squares	Mean square
A. Square at lower level of nitrogen.					
Rows	4	9,787.69	2,446.92	19,456.86	4,864.22
Columns	4	55,412.72	13,853.18*	55,328.13	13,832.03
Treatments	4	45,993.74	11,498.44*	66,126.06	16,531.52
Error (a)	12	18,146.00	1,534.67	112,909.43	9,409.12
P	1	0.81	0.81	1.32	1.32
K	1	306.25	306.25	95.06	95.06
PK	1	169.00	169.00	1,447.80	1,447.80
Nit. × P	1	122.10	122.10	666.93	666.93
Nit. × K	1	473.06	473.06	405.02	405.02
Nit. × PK	1	5,076.56	5,076.56	7,881.00	7,881.00
Qual. × P	3	10,417.34	3,472.45	9,069.98	3,023.33
Qual. × K	3	13,382.64	4,460.88	15,520.21	5,173.40
Qual. × PK	3	11,042.24	3,680.75	16,495.53	5,498.51
Error (b)	60	138,730.75	2,312.18	172,364.60	2,872.74
Total	99	355,054.64	—	477,767.93	—
B. Square at higher level of nitrogen.					
Rows	4	43,989.12	10,997.28*	121,172.74	30,293.18*
Columns	4	5,816.61	1,454.15	27,418.91	6,854.73
Treatments	4	27,489.22	6,872.31	77,191.89	19,297.97*
Error (a)	12	38,643.32	3,220.28	46,642.55	3,886.88
P	1	53.29	53.29	64.00	64.00
K	1	14,328.09	14,328.09*	15,951.69	15,951.69*
PK	1	11.56	11.56	234.09	234.09
Qual. × P	4	9,405.79	2,351.45	14,122.78	3,530.70
Qual. × K	4	9,036.79	2,259.20	18,242.49	4,560.62
Qual. × PK	4	4,550.92	1,137.73	5,434.24	1,358.56
Error (b)	60	112,254.93	1,870.92	139,255.08	2,320.92
Total	99	265,579.64	—	465,730.46	—

Error (a) is the basis for direct comparison of whole-plot treatments, and error (b) for quarter-plot treatments and their interactions with the whole-plot (nitrogenous) treatments. Nit. × P, etc. are interactions of the quarter-plot treatments with nitrogen, irrespective of the form in which the nitrogen is applied. Qual. × P, etc. are differential responses to the quarter-plot treatments on plots receiving nitrogen in different forms.

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The analyses of variance for "sampling yields" and "actual yields" are given in Tables VIII and IX, fractions significantly exceeding that ascribable to experimental error being marked with an asterisk.

Table IX. *Actual yields* ( $\frac{1}{4}$  lb. per plot).

Fraction	Degrees of freedom	Grain		Straw	
		Sum of squares	Mean square	Sum of squares	Mean square
A. Square at lower level of nitrogen.					
Rows	4	2,205.04	551.26	1,533.04	383.26
Columns	4	2,161.84	540.46	8,194.24	2048.56*
Treatments	4	10,175.44	2543.86*	13,073.84	3268.46*
Error	12	5,808.52	484.04	8,387.92	698.99
Total	24	20,351.84	—	31,189.04	—
B. Square at higher level of nitrogen.					
Rows	4	5,519.04	1379.76*	7,429.60	1857.40*
Columns	4	6,080.24	1520.06*	3,246.80	811.70
Treatments	4	2,668.24	667.06*	3,865.20	966.30*
Error	12	1,463.92	121.99	3,838.40	319.87
Total	24	15,731.44	—	18,380.00	—

It will be seen that whole-plot treatments appear effective in all cases when "actual yields" are analysed, but that "sampling yields" fail to show an effect on straw at the lower level and on grain at the higher level of nitrogen. These results are shown in the table of percentage yields (Table X).

Table X.

A. At lower level of nitrogen.								
Grain	O	S	M	N	C	Mean	Standard error (cwt. p. a.)	Mean
Actual	86.4	99.6	101.6	110.5	101.9	100.0	3.79	23.21
Sampling	90.2	103.1	102.7	107.7	96.3	100.0	2.50	22.93
Straw								
Actual	86.4	101.6	98.3	113.7	100.0	100.0	4.49	23.51
Sampling	88.4	101.6	103.2	110.1	96.7	100.0	6.06	23.37
B. At higher level of nitrogen.								
Grain	U	S	M	N	C	Mean	Standard error (cwt. p. a.)	Mean
Actual	97.0	96.3	100.0	106.3	100.4	100.0	1.68	26.19
Sampling	93.7	98.0	99.5	105.1	103.6	100.0	3.12	26.57
Straw								
Actual	94.3	97.7	100.0	107.5	100.6	100.0	2.80	25.50
Sampling	94.0	95.1	94.6	106.3	110.0	100.0	3.39	26.89

O=no nitrogen; S=sulphate of ammonia; M=muriate of ammonia; C=cyanamide; N=nitrate of soda; U=urea.

The information lost is in each case the significant superiority of nitrate of soda to other sources of nitrogen, found in all cases for "actual

yields," but only for grain at the lower level for "sampling yields." At the higher level of nitrogen the "sampling yields" of straw show both cyanamide and nitrate of soda significantly above the other three forms of nitrogen. This difference in the position of cyanamide is curious, but is perhaps due to the partial removal of weeds from sampling sheaflets, as in the oats experiment. It is frequently claimed for cyanamide that it inhibits the germination of weed seeds: if there were a real lessening of the weight of weeds on plots treated with this fertiliser, the effect would be that observed.

The sampling method is shown to better advantage in the quarter-plot results. It will be remembered that the quarter-plots were only 1/160th acre in area, and could hardly have been dealt with by large-scale methods. The quarter-plot treatments were identical for each whole plot: (1) no additional treatment; (2) superphosphate; (3) sulphate of potash; (4) both superphosphate and sulphate of potash: the allocation of the four treatments to the quarter-plots within any plot was at random. The analyses of Table IX show that neither phosphate nor potash was effective at the lower level of nitrogen, but that at the higher level there was a significant response to potash both in grain and straw. As Table XI shows, this response was a depression in yield. Its magnitude was quite small—5.88 per cent. for grain and 6.14 per cent. for straw—but the low standard error makes even so small a difference significant. This is a striking demonstration of the efficiency of the experimental arrangement, as well as an example of the manner in which sampling can act as a valuable auxiliary to large-scale harvesting methods.

No differential responses to potash or phosphate on plots bearing different forms of nitrogen were detected, as is shown in the analyses.

Table XI.

	O	P	K	PK	Mean	Standard error
A. At lower level of nitrogen (percentage of mean yield).						
Grain	100.84	100.15	99.11	99.90	100.00	2.74
Straw	100.82	98.63	99.24	101.30	100.00	3.00
B. At higher level of nitrogen.						
Grain	102.85	103.04	96.79	97.32	100.00	2.13
	102.94		97.06			
Straw	102.50	103.64	97.11	96.75	100.00	2.34
	103.07		96.93			

## 3. ROTHAMSTED WHEAT EXPERIMENT.

The wheat experiment of 1928-9 was designed to give information as to the effect of applying sulphate and muriate of ammonia as top dressings to four different varieties of wheat. The top dressings were given either early (March 18), late (May 13), or at both these dates. Owing to the severe frosts of February and March 1929 the plant was very thin, and later the plots became infested with Black Bent (*Alopecurus agrostis*). The weediness was much more marked at one side of the experimental area than at the other, and tended to increase still further what must in any case have been a large experimental error. As a result no treatment or variety differences could be regarded as significant, and no more information was obtained by the large-scale than by the sampling method. Table XII gives the sampling and experimental errors per plot, expressed as percentages of the mean yield.

Twenty-four metre-lengths of drill were cut from each of the plots. The area of each plot was 1/55th acre.

Table XII.

	Grain		Straw	
	(a)	(b)	(a)	(b)
(a) "Sampling yields":				
Experimental error	11.69	20.39	14.41	16.89
Sampling-error		5.84		6.73
(b) "Actual yields":				
Experimental error	9.68	22.48	9.99	15.14

Columns (a) and (b) show the plot errors for varietal and treatment comparisons respectively.

## 4. WELLINGORE BARLEY EXPERIMENT.

By courtesy of G. H. Nevile, Esq., of Wellingore Hall, Lincs., an experiment was carried out on Lincoln Heath, near the village of Wellingore. This consisted of sixteen plots, bearing eight different treatments in duplicate—no artificial fertilisers, and any one, two, or three of the following dressings: sulphate of ammonia at 1 cwt. per acre, sulphate of potash at 1 cwt. per acre, and superphosphate at 3 cwt. per acre. The plots were each 1/60th acre, and were harvested only by a sampling method. Forty half-metre lengths of drill were cut from each plot, but actually there were only four sampling units—i.e. four independently located parts of the sample (2). The procedure was to select four drill-rows at random from each plot (discarding edge-rows), and

then to cut 10 half-metre-lengths as shown in the diagram (Fig. 1). The measuring-rod was that used at Rothamsted, 2 half-metres being separated by a metre.

A constant number of paces separated successive placings of the rod. It is readily seen that this method gives a complex sampling-unit which involves four rows, and that four such sampling-units must provide a satisfactorily representative sample of the produce of the plot.



Fig. 1.

The analyses of variance for grain and straw are shown in Table XIII, fractions significantly exceeding that ascribable to experimental error being marked with an asterisk.

Table XIII.

Fraction	Degrees of freedom	Grain		Straw	
		Sum of squares	Mean square	Sum of squares	Mean square
Blocks	1	6,172.07	6,172.07	744.27	744.27
K	1	2,217.82	2,217.82	2,960.04	2,960.04*
P	1	962.94	962.94	1,567.67	1,567.67*
N	1	17,797.23	17,797.23*	29,745.47	29,745.47*
PK	1	199.52	199.52	345.73	345.73
NK	1	826.56	826.56	2,629.77	2,629.77*
NP	1	14,475.10	14,475.10*	11,469.07	11,469.07*
NPK	1	2,044.73	2,044.73	2,604.18	2,604.18*
Error	7	4,551.94	650.28	2,021.19	288.74
Within plots	48	22,936.90	477.85	22,740.95	473.77
Total	63	72,184.81	—	76,828.34	—

The sampling-error per plot was 5.31 per cent. for grain, and 5.78 per cent. for straw; and the experimental errors 6.19 per cent. and 4.51 per cent. respectively.

It is interesting to note that for grain two, and for straw no less than six of the treatment items were found to be significant. The low experimental errors which make the experiment so useful can doubtless be ascribed to the exceptional uniformity of the soil and the plant. That the plant was uniform is further shown in the magnitude of the sampling-errors, which are of the same order as in Rothamsted experiments where 30 or more metre-lengths were taken from each plot.

## DISCUSSION.

The results are summarised in Table XIV. The experiments with barley certainly justify the claims made in an earlier paper for the accuracy and usefulness of the sampling method described. The sampling-error per plot has been rather more than 5 per cent. of the mean yield; the experimental error, as for grain at the lower level of nitrogen in the barley experiment, may actually be lower than the corresponding large-scale figure; little information has been lost which a large-scale method would have given; plots were successfully dealt with which would have been much too small for large-scale experimentation; and the large-scale methods were entirely dispensed with in an outside experiment which yielded a great deal of information as to the effects of various fertiliser combinations. Further advantages are that edge-rows can be discarded without the necessity of removing them; losses in the stook and in the stack are avoided; results are available sooner than would normally be the case with stacked corn; and the bulked produce of the independently located sampling-units constitutes an excellent sample for analytical work.

Table XIV.

Crop	Size of sample (metres)	Area of plot (acre)	Sampling-error (% per plot)	Experimental error (% per plot)	
				(a) "Sampling yields"	(b) "Actual yields"
Wheat:					
1. Grain	24	1/55th	5.84	11.69, 20.39	9.68, 22.48
2. Straw			6.73	14.41, 16.89	9.99, 15.14
Oats:					
1. Grain	30	1/40th	5.87	12.36	11.07
2. Straw			5.51	13.11	7.90
Barley:					
(a) 1. Grain	32	1/40th	5.53	5.58	8.46
2. Straw			5.58	13.56	10.04
(b) 1. Grain	32	1/40th	4.99	6.98	3.77
2. Straw			5.09	7.58	6.26
Barley (Wellingore):					
1. Grain	20	1/60th	5.31	6.23	—
2. Straw			5.78	4.51	—

The experiments with winter-sown cereals were somewhat less pleasing, but the higher sampling-error per plot can almost certainly be ascribed to the depletion of plant by the severe frosts of the winter 1928-9. Little useful information was derived from the wheat experiment. From the results of the oats experiment, however, it is shown that the sampling method can be used to give the weight of straw freed from weeds, and also an estimate of the effect of various fertilisers on weed growth.

Where large-scale equipment is already in use it could hardly be suggested that this should be entirely replaced by the apparatus necessary for the sampling method. The results of the 1929 experiments show, however, that sampling for yield might well be adopted as an auxiliary method, and where no large-scale machinery is already available it would further recommend itself through the relative cheapness of the necessary equipment. It solves the problem of harvesting complex experiments on farms at some distance from the organising station, and by thus permitting the repetition of experiments on many types of soil, greatly enhances their value.

The practicability of dealing with small plots is an important point. It has been shown by Roemer<sup>(4)</sup> and others that for a given experimental area, to be used for the comparison of a given number of varieties or treatments, it is of much greater advantage to increase the number of replications than to increase the size of the individual plot. In other words, the loss of accuracy arising from reduction in the size of the individual plot is more than counterbalanced by the gain from a higher degree of replication. The labour of sampling, however, from the experimental area may not be greatly increased by an increase in the number of plots into which it is divided, and the absolute size of the individual plot does not in any way affect the practicability of sampling. The extent to which the total size of sample taken from the area is altered depends, of course, on the nature of the variations in yield per unit length of drill over the area. Thus if the mean yield of a small plot (for constant treatment), and the variability within the plot, were fairly constant throughout, it would be necessary to take almost as many sampling-units from a small plot as from a large plot. If, on the other hand, mean fertility varied considerably between small plots, it would be possible to reduce the number of sampling-units when the plot-size is reduced. It may be said in general that the number of sampling-units to be taken from a small plot can be at least  $(n - 1)$  less than the number taken from a larger plot, where the areas are in the ratio  $1:n$ , provided that it proved profitable to subdivide the larger plot into  $n$  parts for the purpose of sampling. The test of the advantage gained by subdivision is the significance of the difference between the mean squares for "within subdivisions" and "between subdivisions," as explained on p. 379.

It may be noted that it is not essential to take a large number of sampling-units from each plot, though in exploratory work such as that described it was desirable in order to obtain an accurate estimate of the sampling-error, of the advantage gained by subdivision of plots, etc. When such preliminary work has been completed, it should be sufficient

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to take two or three complex sampling-units from each plot, the size of the sample remaining, of course, unchanged.

In conclusion it should be pointed out that for convenience in sampling the distance between drills should be not less than 7 in., and that where choice is possible, a stiff-strawed variety should be grown, since lodged corn is very difficult to sample adequately.

#### SUMMARY.

1. Four cereal experiments, comprising 210 plots each about 1/40th acre in area, were harvested by a sampling method. Three of the experiments were later harvested by large-scale methods, so that a direct comparison could be made.

2. The field technique is described, and an account is given of the small combined thresher and winnower which was constructed for the purpose of dealing rapidly with the numerous small sheaflets.

3. The results are analysed in detail and it is shown that the sampling-errors per plot lie between 5 and 6 per cent. of the mean yield, and that these errors are sufficiently low for there to be little loss of information.

4. The relative advantages of large-scale and sampling methods are discussed, with special reference to the possibility of dealing with large numbers of very small plots, and of carrying out complex experiments on farms distant from the organising station.

Finally, it is with pleasure that we record our indebtedness to Messrs Garner, Parbery, Hansen, Leonard, French, Weston, Cole and others for assistance in the field and with the threshing; to Dr J. Wishart for providing the analyses of "actual yields," and to Dr R. A. Fisher for constant readiness to offer suggestions which were always valuable.

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